Experimental Study of EDM and Electromagnetic Field Assisted EDM for Ni Alloy: AComparative Study

Pawan Kumar Yadav[1], Pravendra Kumar[2]and Dr. S.K.S. Yadav[3*]
[1]M. Tech Student, Mechanical Engineering Department, H.B.T.U. Kanpur, U.P. (India) – 208002
[2]JRF, DST Project, Mechanical Engineering Department, H.B.T.U. Kanpur, U.P. (India) - 208002
[3*]Assistant Professor, Mechanical Engineering Department, H.B.T.U. Kanpur, U.P. (India) - 208002
Email: pawanhbtu@gmail.com,pravendrahts2012@gmail.com, sanjeevyadav276@gmail.com

Abstract

Electromagnetic Field Assisted Electrical Discharge Machining (EMFAEDM) process is a hybrid machining process classified under the category of collaborative hybrid machining processes. In this process material is removed by Electrical Discharge Machining process whereas Electromagnetic field developed around the machining area assists in expelling the debris from machining gap fast and easily.In the present research work machining has been performed on Ni-alloy workpiece with and without application of electromagnetic field during Electrical Discharge Machining. Further, the comparisons of EDM with electromagnetic field assisted EDM have been made for finding the role of electromagnetic field. During experimental study input parameters viz. Pulse current (Ip), Pulse on time (T_{ON}), Pulse off time (T_{OFF}) and varying electromagnetic field were selected. After pilot experiments the range of input parameters for Ni-alloy workpiece were selected as Pulse current (6-12 A), Pulse-on-time (60-120 µs), Pulse-off-time (15-90 µs). After finding the range of input parameters, experiments were performed using Taguchi's L9 orthogonal array for finding the effects of input parameters on output parameters (MRR and surface roughness (R_a)). After experimentation, the experimental results reveal that the MRR increases with an increase of pulse current (I_P) and pulse on time (T_{ON}) for both the processes (i.e. with and without Electromagnetic field). Simultaneously the surface roughness decreases with an increase in pulse off time and electromagnetic field. Further, higher MRR and low surface roughness (i.e. high surface quality) was observed with electromagnetic field assisted EDM as compare to EDM.

Keywords:Electromagnets, electromagnetic field, hybrid machining, EDM, MRR, R_a

1. INTRODUCTION

Electrical Discharge Machining (EDM) is a unique machining process capable of removing material in the sub-grain size from materials irrespective of their hardness.This process is valuable in the manufacturing of miniaturized products where industries demand for machining advanced materials such as tool steel, tungsten carbide, titaniumetc used in making of tools for micro-scale machining, mould and die making, diesel fuel injector fabrication and surgicalinstruments manufacturing. EDM is one of the widely used non-conventional machining processes for machining of advanced materials. However, the existing material removal rates (MRR) for EDM varies from 0.6-6.0 mm^3/h , which is far below the desired minimum level of 10-15 mm^3/h required for industrial viability. Efforts have been made to improve the MRR of the EDM process through research in several key areas [13].

The use of magnetic field in non-traditional machining process was successfully introduced by many researchers in different ways. Wang et al. [2005] studied development of Magnetic abrasive finishing (MAF) and magnetic abrasive flow finishing (MAFF) methods to polish metal, ceramic and composite materials up to the mirror surface.Yan et al. [2004] successfully attempted in improving the quality of EDM machined surface by introducing magnetic abrasives in the machining area. Lin and Lee [2008] applied the magnetic field over EDM process and concluded that debris removal from the machining gap improves the EDM process stability and also the efficiency, quality of machined surface especially during high discharge energy regime.The selection and modification of EDM with magnetic field assisted has shown that it directly and indirectly affects MRR through alteration of discharge crater characteristics. Finally, improvements in debris removal strategies have yielded promising increases in MRR due to the adverse effects debris can have on the stability of the discharge process when it is allowed to build up in the inter-electrode gap. V.S. Naidu et al. [2014] experimentally studied varying Electromagnetic field assisted die sinking EDM on Ti-6Al-4V workpiece using copper electrode. They observed that the application of electro-magnetic field showed drastic increase in the MRR by 25.7 % over conventional EDM.Wang A. C. et al [2005] have done investigation on comparisons between tap water, distilled water, de-ionized water, and kerosene, all of which point to higher MRR, lower electrode wear, and improved surface finishes with water as the dielectric versus kerosene. F. Klocke et al. [2004] studied the modification of dielectric fluids through the addition of suspended powders has been used to improve surface quality, MRR and tool wear rates. The primary goal of most powder-mixed dielectric studies is to improve surface finishes in EDM, which can decrease overall part production time by reducing or eliminating the need for post-machining polishing. However, improvements in actual MRR during the EDM process are often small with the addition of powders to the dielectric fluid and come as an indirect result of the efforts to improve surface characteristics. Because of this, machining times are not significantly reduced through the use of powder-mixed dielectrics.

In the present work, a self-designed setup consisting of four electromagnets was placed surrounding the machining area of workpiece in the dielectric tank. The experiments were conducted using Taguchi's L9 orthogonal array with and without application of magnetic field in order to find the effect of application of magnetic field on performance of existing EDM process and also on the surface quality of the machined surface.

ISBN: 978-93-80689-28-9

2. EXPERIMENTAL DETAILS

The experimental study was performed on SPARKONIX ZNC EDM. In order to develop electromagnetic field an electromagnet was made using a solid circular ferrite core. The ferrite core was wound by a specific number of turns of copper wire. In order to make the electromagnet perfectly safe from short circuiting, the copper coil is surrounded by insulating tape and then it is covered by a layer of m-seal so that the copper coil remain inside whereas the face of ferrite core remain uncovered and electromagnetic field is generated at this face.Four such electromagnets are placed on a stand made of mild steel stripsfacing towards center as shown in Fig.1.

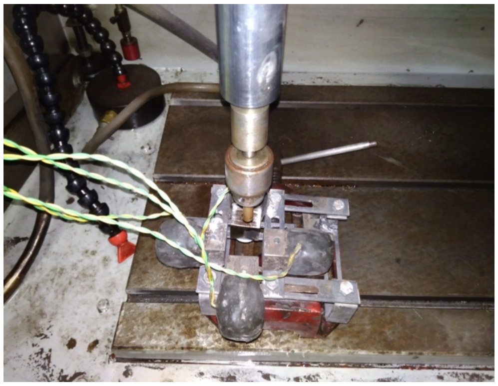

Fig. 1: Experimental setup of electromagnetic field assisted EDM

This whole attachment is mounted around the vice in such a way that the workpiece to be machined remain at center (at equal distance from the face of each electromagnet). Each electromagnet is incorporated with positive (+ve) and negative terminal (-ve) for DC power supply to generate electromagnetic field. 230 V A.C. power supply is converted to variable DC power supply by means of a variac. The intensity of magnetic field is varied by varying the DC voltagesupply to electromagnets. Ni alloy is selected as workpiece material as it is widely used in aerospace, automobile, precision measuring instruments, strain gauges, electrically heated appliances etc. A solid copper tool of 12 mm diameter and 30 mm length is used for machining. Machining parameters used in this experimental study are pulse current (I_P), pulse-on-time (T_{ON}), pulse-off-time (T_{OFF}) and DC voltage (V) supplied to electromagnets. Material removal rate (MRR) and surface roughness (R_a) are selected as response (output) parameters.A set of pilot experiments were performed for selection of range of input parameters.

Table 1: Machining parameters and their levels

S. No.	Parameter	Level 1	Level 2	Level 3
1.	Pulse Current (A)	6	9	12
2.	Pulse-on-time (μs)	60	90	120
3.	Pulse-off-time (μs)	15	45	90
4.	DC voltage supply to electromagnets (V)	60	80	100

The experiments were designed using Taguchi's L9 orthogonal array and the experimental data obtained without considering electromagnetic field and with considering electromagnetic field is tabulated in Table 2 and Table 3 respectively.

Table 2: Taguchi's L9 OA without considering Electromagnetic field

S. No.	I_p	T_{ON}	T_{OFF}	MRR (g/min)	R_a (μm)
1.	6	60	90	0.0034	5.64
2.	6	90	45	0.0053	7.16
3.	6	120	15	0.0025	6.89
4.	9	60	45	0.0068	7.41
5.	9	90	15	0.0084	9.87
6.	9	120	90	0.0023	8.91
7.	12	60	15	0.0079	7.31
8.	12	90	90	0.0115	8.87
9.	12	120	45	0.0129	9.18

Table 3: Taguchi's L9 OA with considering Electromagnetic field

S. No.	I_p	T_{ON}	T_{OFF}	V	MRR (g/min)	R_a (μm)
1.	6	60	90	60	0.0084	4.72
2.	6	90	45	80	0.0231	6.08
3.	6	120	15	100	0.0496	6.58
4.	9	60	45	100	0.0149	6.96
5.	9	90	15	60	0.0773	9.06
6.	9	120	90	80	0.0531	7.59
7.	12	60	15	80	0.0378	6.87
8.	12	90	90	100	0.0347	8.31
9.	12	120	45	60	0.0684	8.38

3. RESULTS AND DISCUSSION

3.1 Effect of Electromagnetic Field on MRR

From the experimental data observed, a comparison graph of MRR is plotted as shown in Fig. 2, which shows the effect of electromagnetic field on MRR.

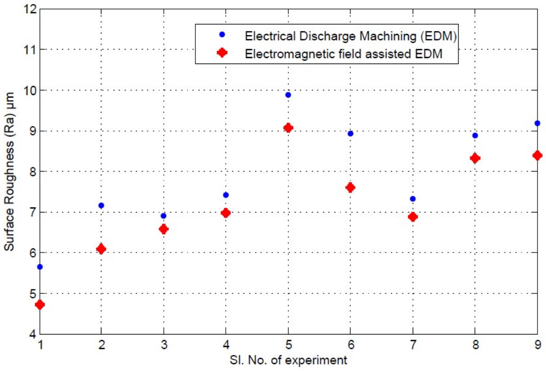

Fig. 2: Comparison of MRR in EDM and EMFAEDM

From Fig. 2, it is observed that the application of electromagnetic field with EDM significantly improves MRR. In all the nine experiments conducted, MRR of electromagnetic field assisted EDM process is more than the conventional EDM process.

3.2 Effect of Electromagnetic Field on R_a

Similarly to MRR, a comparison graph of surface roughness (R_a) obtained in EDM and Electromagnetic field assisted EDM is plotted as shown in Fig. 3. From this graph, it is observed that surface roughness of Electromagnetic field assisted EDM is lower than the conventional EDM Process.

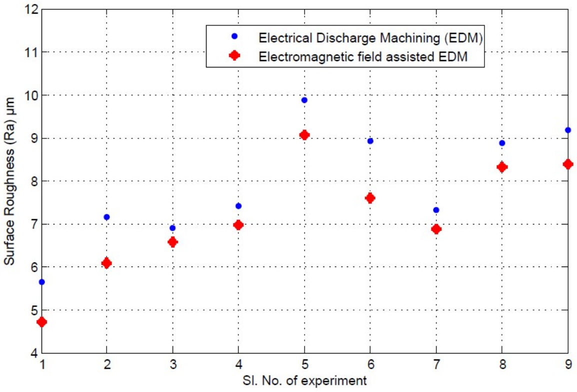

Fig. 3: Comparison of R_a in EDM and EMFAEDM

3.3 Effect of input parameters on MRR

Figure 4 shows the main effectsplot for MRR in electromagnetic field assisted EDM process. The MRR is found to be increased with increase in pulse current (I_P) and pulse-on-time (T_{ON}). The basic reason behind it is that current and pulse-on-time is directly proportional to the spark discharge energy. Main effects plot for MRR shows decreasing trend with pulse-off-time (T_{OFF}) because of re-solidification of debris particles on the machined surface. On the other end, electromagnetic field voltage shows first decreasing then increasing trend.

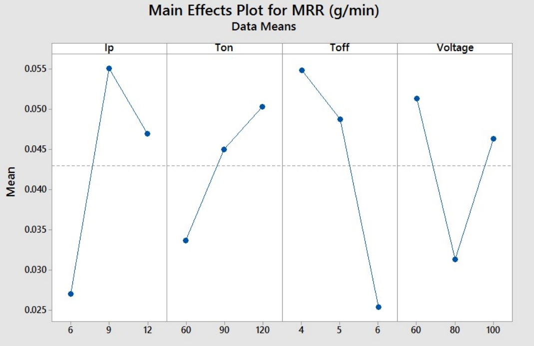

Fig. 4: Effect of I_P, T_{ON}, T_{OFF} and electromagnetic field Voltage on MRR

3.4 Effect of input parameters on surface roughness (R_a)

Figure 5 shows the main effects plot for surface roughness (R_a) in electromagnetic field assisted EDM process. Pulse current (I_P) and pulse-on-time (T_{ON}) shows increasing trend for surface roughness (R_a) whereas pulse-off-time (T_{OFF}) shows decreasing trend to surface roughness (R_a). The electromagnetic field voltage shows nearly decreasing trend to surface roughness (R_a).

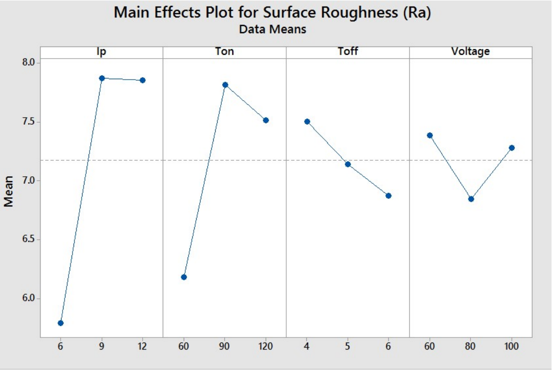

Fig. 5: Effect of I_P, T_{ON}, T_{OFF} and electromagnetic field Voltage on MRR

3.5 SEM analysis of machined surface

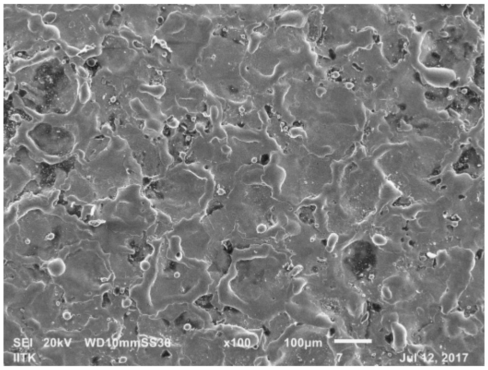

Fig. 6: SEM micrograph of Ni alloy machined with EDM at x100

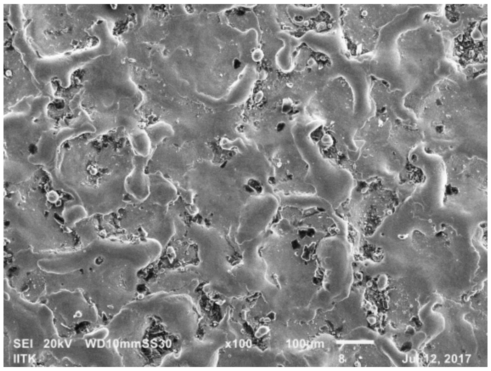

Fig. 7: SEM micrograph of Ni alloy machined with EMFAEDM at x100

Figure 6 and Figure 7 shows the microstructure of machined surface with Electrical discharge machining (EDM) and Electromagnetic field assisted electrical discharge machining (EMFAEDM) respectively. A little consideration on both the micrographs will show that the size of craters in magnetic field assisted EDM process is bigger in comparison to that of conventional electrical discharge machining (EDM) process which is evident of increased MRR in electromagnetic field assisted EDM process. In order to further analyze the composition of machined surface EDS and mapping of machined surface (for both EDM and EMFAEDM) is done.

Table 4: EDS results for Ni alloy machined with EDM

Chemical formula	mass%	Atom %	Sigma	Net	K ratio	Line
C	24.61	58.83	0.07	4913	0.0024658	K
O	3.18	5.70	0.08	1984	0.0033817	K
Cr	16.04	8.85	0.14	26977	0.0439312	K
Co	13.96	6.80	0.16	13743	0.0353673	K
Ni	37.85	18.51	0.26	32618	0.1001350	K
Mo	4.36	1.30	0.13	6612	0.0076424	L
Total	100.0	100.0				

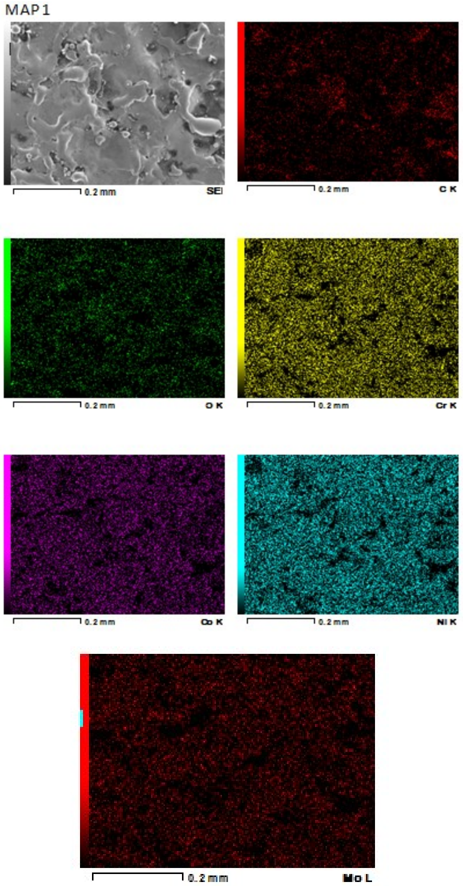

Fig. 8: Mapping of C, O, Cr, Co, Ni and Mo respectively on machined surface with EDM

Table 5: EDS results for Ni alloy machined with EMFAEDM

Chemical formula	mass %	Atom %	Sigma	Net	K ratio	Line
C	26.32	60.21	0.05	15106	0.0015394	K
O	4.21	7.24	0.05	7181	0.0024854	K
Cr	15.39	8.13	0.08	73080	0.0241648	K
Co	13.76	6.42	0.09	38283	0.0200049	K
Ni	35.55	16.64	0.15	86578	0.0539677	K
Mo	4.77	1.37	0.08	20683	0.0048543	L
Total	100.0	100.0				

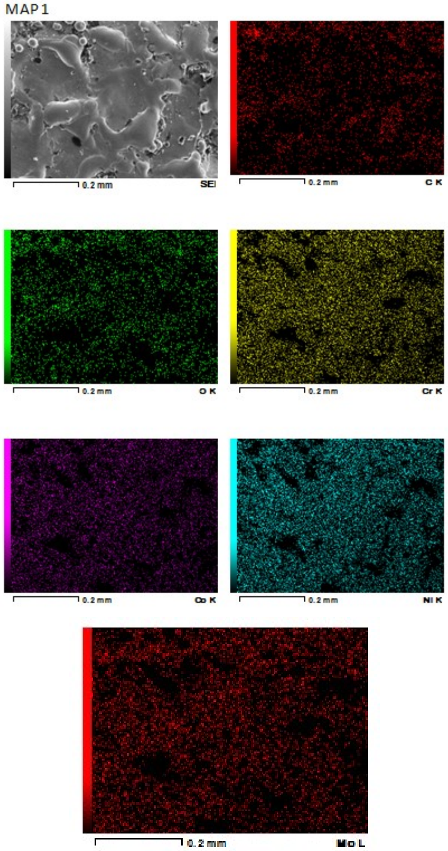

Fig. 9: Mapping of C, O, Cr, Co, Ni and Mo respectively on machined surface with EMFAEDM

From EDS data and mapping images it is evident that there is no deposition of tool material on the machined surface in both the cases i.e. EDM and EMFAEDM. However there is slightly more carbon deposition on the surface machined with EMFAEDM as compared to that machined with EDM.

4. CONCLUSIONS

In context to applying electromagnetic field in conventional EDM process following conclusions is drawn:

- i The application of electromagnetic field with conventional EDM process gives increased MRR and improved surface finish.
- ii About 6.35 times more MRR (in average) is observed in Electromagnetic field assisted EDM process in comparison to convention EDM Process.
- iii About 1.5 times less surface roughness (R_a) value is observed in EMFAEDM process.
- iv Pulse current and pulse-on-time directly affects both the MRR and surface roughness (R_a) whereas pulse-off-times inversely affects both MRR and R_a.
- v Electromagnetic field has nearly increasing effect on MRR whereas nearly decreasing effect on surface roughness.
- vi EDS and mapping results show that there is no deposition of tool material on the machined surface of workpiece.

References

1. Bruijn D., Delft H.E. and Pekelharig A.J., "Effect of amagnetic field on the gap cleaning in EDM," CIRPAnnuals, Vol. 27 (1), pp. 93–95, 1978.
2. Gangadhar A., Shunmugam M.S. and Philip P.K.,"Pulse train studies in EDM with controlled pulserelaxation," International journal of Machine Tools and Manufacture, Vol. 32, pp. 651–657, 1992.
3. Soni J. S. and Chakraverti G., "Machining characteristics of titanium with rotary electro-discharge machining," Wear, Vol. 171, No. 1-2, pp. 51–58, 1994.
4. Kim J. D., Jin D. X. and Choi M. S., "Study on theeffect of a magnetic field on an electrolytic finishingprocess," International Journal of Machine Tools and Manufacture, Vol. 37, No. 4, pp. 401–408, 1997.
5. DoloiB. and BhattacharyaB., "Electrochemical Discharge Machining of Non-Conducting Ceramics",Defence Science Journal, Vol. 49, No. 4, pp. 331-338, 1999.
6. K.H. Ho and S.T. Newman, "State of the art Electrical Discharge machining (EDM)", International Journal of Machine Tools & Manufacture, Vol. 43, pp. 1287–1300, 2003.
7. ShuK. M. andTuG.C., "Study of electrical Discharge grinding using Metal Matrix Composite Electrodes", International Journal of Machine Tools & Manufacture, Vol. 43, 2003.
8. Fenggou C. and Dayong Y.,"The study of highefficiency and intelligent optimization system in EDM sinking process," Journal of Materials Processing Technology, Vol. 149, pp. 83-87, 2004.
9. Yan B.H., Chang G.W., Chang J.H. and Hsu R.T.,"Improving electrical discharge machined surfaces using magnetic abrasive finishing," Machining Science and Technology, Vol. 8 (1), pp. 103–118, 2004.
10. Wang, Y. and Hu, D., "Study on the inner surface finishing of tubing by magnetic abrasive finishing," International Journal of Machine Tools and Manufacture, Vol. 45, No. 1, pp. 43–49, 2005.
11. Kunieda B., Lauwers, Rajurkar K.P. and Schumacher B.M., "Advancing EDM through fundamental insight into the process, CIRP Annuals, Vol. 54, Issue. 2, pp. 599-622,2005.
12. JainV.K. and G. Mote Rakesh, "On the temperature and specific energy during Electro Discharge Diamond Grinding (EDDG)",Int J AdvManufTechnol, Vol.26, pp. 56–67, 2005.
13. Uruarte, L., Herrero, A., Ivanov, A., Oosterling, H., Staemmler, L., Tang, P.T., and Allen, D., "Comparison between micro fabrication technologies for metal tooling," Special Issue paper, Prc. IMechE 220, pp. 1665-1676, 2006.
14. Uruarte L., Herrero A., Ivanov A., Oosterling H., Staemmler L., Tang P.T. and Allen D., "Comparison between micro fabrication technologies for metal tooling," Special Issue paper, Prc. IMechE 220, pp. 1665-1676, 2006.
15. KumarSanjeev, "Prediction of Wear and Surface Roughness in Electro-Discharge Diamond Grinding", Journal of Materials Processing Technology, Vol. 191, pp.206–209, 2007.
16. Lin, Y.C., and Lee, H.S., "Machining characteristics of magnetic force-assisted EDM," International Journal of Machines Tool and Manufacture, Vol.48,pp. 1179-1186, 2008.
17. YadavS.K.S. and Narayana V., "Experimental study and parameter design of electro-Discharge diamond grinding", International Journal of Advanced Manufacturing Technology, Vol. 36 (1-2), pp. 34-42, 2008.
18. Rahman M., Jahan M.P. and Saleh T., "Development,Modeling, and Experimental Investigation of Low Frequency Workpiece Vibration-Assisted Micro-EDM of Tungsten Carbide", Journal of Material Processing Technology, Vol. 132, pp.1-8, 2010.
19. Yadav S K S and Yadav V.,"Multi-objective optimization of electrical Discharge diamond cutoff grinding (EDDCG) using Taguchi Method", International Journal of Manufacturing Technology and Industrial Engineering, Vol.1, pp. 193–198, 2010.
20. Veeresh KumarG. B., RaoC. S. P., SelvarajN. andBhagyashekarM. S., " Studies on Al6061-SiC and Al7075-Al2O3 Metal Matrix Composites", Journal of Minerals & Materials Characterization & Engineering, Vol. 9, No.1, pp.43-55, 2010.
21. Heinz K., Kapoor S.G., De-Vor R.E. and Vijay S.,"An Investigation of Magnetic Field-Assisted MaterialRemoval in Micro-EDM for Nonmagnetic Materials,"Journal of Manufacturing Science and Engineering, Vol.133, 2011.
22. Joshi S., Govindan P., Malshe A. and Rajurkar K.,"Experimental characterization of dry EDM performed in a pulsating magnetic field," CIRP Annals - Manufacturing Technology, Vol. 60, pp. 239–242, 2011.
23. Teimouri R., and Baseri H., "Experimental study of rotary magnetic field-assisted dry EDM with ultrasonic vibration of workpiece," International Journal on Advance Manufacturing Technology, Vol. 67, pp. 1371-1384, 2012.
24. M. K. Satyarthi, Pulak M. Pandey, "Modeling of material removal rate in electrical Discharge grinding process", International Journal of Machine Tools & Manufacture, Vol. 74, 2013.
25. Naidu Vignesh S., Vipindas K., Manu R. and Mathew Jose, "Experimental Study on Varying Electromagnetic Field Assisted Die Sinking EDM", 26th AIMTDR, pp. 339 (1-6), 2014.
26. Yulei Fu, "Study on Influence of Electrode Material on Hole Drilling in Micro-EDM", 18th CIRP Conference on Electro Physical and Chemical Machining (ISEM XVIII).
27. Sharanya Nair and Nehal Joshi, "Preparation of Al 6061/ SiC Metal Matrix Composite (MMC) using stir casting Technique", IJARIIE-ISSN (O)-2395-4396, 2015.
28. Rajaneesh N. Marigoudar and KanakuppiSadashivappa, "Effect of Machining Parameters on MRR and Surface Roughness in Machining of ZA43/ SiCp Composite by WEDM" International Journal of Applied Science and Engineering, Vol. 11, Issue: 3, pp. 317-330, 2013.
29. JainV.K., Advanced Manufacturing process, Allied Publication.
30. SeropeKalpakjian, Manufacturing Engineering and Technology, Pearson publication.